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SOME DATA ON THE OPERATION OF HIGH-PRESSURE BOILERS WITH NATURAL CIRCULATION AT USSR ELECTRIC POWER STATIONS

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/Figures are appended_7

The high-pressure boiler units installed in USSR electric power stations are marked by great diversity of thermal and boiler design. They differ in capacity (40-230 tons/hr), steam pressure and temperature (65-140 atm, 470-510°C), and fuel properties (V^g equals 4-70%; A^c equals 18-50%; W^p equals 6-55%).

The peculiarities of our fuels create corresponding difficulties in operating high-pressure boilers at USSR power stations in comparison, for example, with conditions at US stations, where such "heavy" fuels as "ASh" /anthracite dust_7, Moscow coal, coal dressing by-products with high ash content, milled peat, etc., are comparatively unknown.

Structural variations notwithstanding, high-pressure boilers retain the main features of the more modern medium-pressure boilers: moderate furnace heat intensities (104,000-175,000 cal/cum/hr); water-wall /wall screening_7 tubes of external diameters 70 and 83 mm (rarely 60 mm) with relative pitch 1.2-2.6 (up to 3.6 in peat boilers); convection superheaters, etc. Some boilers under construction and others recently put into service have radiation superheaters located on the furnace walls or in the upper part of the furnace chamber.

The foreign high-pressure boiler units installed in our country were reconstructed owing to substantial defects in their original construction and differences in fuel. In several cases, the furnace volume had to be increased to obtain heat intensities accepted as normal in the USSR.

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Furnaces with heat intensities of 240,000-250,000 cal/cum/hr, which is typical of foreign designs, do not ensure cinder-free operation with most of our fuels.

Increasing the efficiency of reconstructed units usually called for the remodeling of the back sections. Many boilers had a flue-gas temperature of 200-220°C. During reconstruction, as a rule, decisions were made which did not entail excessive modification of the original designs. In many cases, heat losses in the flue gases remained large.

The granulaters of many boilers made by foreign firms were replaced by "kholodnyye voronki" [cold funnels ?]. In some boilers, the furnaces were adapted for liquid slag removal.

The absence of superheat regulators and mixing headers on the steam superheaters of some foreign high-pressure boilers must be considered a defect to be remedied during reconstruction. Unfortunately, such necessary work is sometimes still not undertaken, the boiler being relied upon to operate satisfactorily in its original condition. Experience of boiler shutdowns, where the superheater was retained without superheat regulation and without mixing headers, and the use of units with purely counterflow superheaters for t''_n = 500°C shows that it is necessary to act more in accordance with our own experience, utilizing the theoretical research on boiler technology problems available in the USSR.

Soviet high-pressure boilers made by the "Krasnyy kotel'shchik" Plant in Taganrog proved more reliable and more economical than foreign boilers. Their output is 230 tons/hr at 100 atm and 510°C.

Utilization of Boiler Units

As can be seen from the boiler unit utilization graphs (Figure 1), the operating time factor (the ratio of the mean number of hours of operation to the calender number of hours) and the utilization factors (according to the procedure adopted in the Ministry of Electric Power Stations) show that some electric power stations are still making insufficient use of their high-pressure boiler equipment. In many cases, this is due to load conditions in the systems. At the same time, the accounting data on the mean monthly loading of the boiler units show that their planned output was attained at almost all stations.

During their initial period of operation, almost all high-pressure boiler installations were frequently allowed to be shut down. Figure 2 shows the number of times one installation was fired up in one month.

In 1947 and 1948, the greatest number of breakdowns occurred in water economizers (42.8%) and steam superheaters (21%). Statistics of accidents and operational breakdowns also show damage to the water-wall tubes and festoon tubes [main water tubes?] and shutdowns caused by failure of auxiliary equipment (Figure 3).

Economic Aspects

According to certain known cases, putting a high-pressure installation into operation had, in the beginning, an adverse effect on the over-all economy of the stations. Later, however, as the new equipment was thoroughly understood and as its reliability increased, the specific fuel consumption dropped considerably, especially in the last months of 1948 (Figure 4).

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It can be seen from the gross and net efficiencies (Figure 5) that the boiler units of most high-pressure stations operated considerably more economically in 1948 than they did in 1947, but still the economy of the better Soviet intermediate-pressure boilers has not been equaled in all cases.

At some stations, even after reconstruction, flue gas and induced draft temperatures in the gas passages are still high. For new boiler units, it is desirable to seek ways of further reducing flue gas temperatures at least to 160°C for moist coal and to 140°C for dry.

The difference between the gross and net efficiencies is still fairly large in some installations. This is due to increased losses of steam and condensate, especially in the initial period of use, and to considerable expenditure of electric power on the needs of the boiler room itself. In particular, the power expended on forced draft is large, due to the wastefulness of forced-draft equipment, and the increased gas flow resistance.

Expenditures on forced draft can be cut by rapid introduction of high-economy flue gas pumps and fans, improving the compactness of the gas passages, and reducing the gas resistance of boiler installations. This can be done, in particular, by improving the aerodynamic shape of the connecting boxes in the air preheater and smokestack section and in the gas passages. It is advisable to investigate the gas velocities in the new boilers with a view to effecting some reduction.

Furnaces

Experience with postwar high-pressure boilers has shown that difficulties in obtaining reliable and economical work with the designed steam parameters were often due to incorrect furnace processes. Unstable combustion when burning "ASh" fuel, abnormal excess air, uneven temperature distribution, and gas velocities constitute the main sources of complications in furnace operation.

At one GRES (State Rayon Electric Power Station) where no desuperheater was fitted, the degree of superheat was reduced by using too little excess air. This in turn had an adverse effect on the furnace process, resulting in afterburning of the pulverized fuel, etc. Normal adjustment and operation of the unit were impossible under such conditions. The remedy was to reduce the heating surface of the superheater by about 20%.

A cause of abnormally high excess air in the furnace and throughout the uptakes has been uncoordinated designs of air intakes in the drying and pulverizing systems, as well as in the furnaces and corresponding gas passages. For example, the first boiler units of many GRES were started with an excess air coefficient as high as 1.75.

The bad effect of induced drafts in the furnace is already well known from experience with medium-pressure boilers. It is still more noticeable at high pressure and especially affects the superheater, which operates at temperatures approaching the limiting values for the metal, and the back heating surfaces, particularly when the feed water temperatures is high.

Hence, special attention should be paid to the outer brickwork, casing, and packing of places where the casing is pierced by tubes or supports. These points should also be taken into consideration by designers.

Experience shows that this is not as yet universal practice. Even when installing a new high-pressure boiler manufactured by the Taganrog Boiler Plant, it was necessary to produce on the site 25 sketches for additional construction to ensure adequate tightness of the unit.

All these arrangements were very simple and doubtless would have been still simpler if the gas tightness requirement had been considered during the design stages.

Slag formation on heating surfaces is now rare. This is the fruit of experience accumulated by Soviet heat engineers in prewar years. However, it still occurs in some reconstructed imported boilers due to inadequate and unsuccessful shielding of combustion chambers.

In connection with the problem of dirt and slag formation on heating surfaces, it should be noted that boiler-building plants are continuing to deliver units without soot blowers, which makes for difficulty in operation.

Circulation

When high-pressure boilers were first introduced, there were dangers which threatened reliable circulation. However, there were hardly any cases in our country of damage to water-wall and festoon tubes caused by defects in circulation systems. This shows the reliability of the circulation systems under normal operational conditions.

In the high-pressure boilers manufactured by the Taganrog and Podol'sk Boiler Plants and in all boilers reconstructed in the USSR, the principle has been to achieve maximum division of the circulation circuits, so that each of the side, front, and rear water walls usually forms independent circuits. Moreover, a fairly free cross section of the drop tubes has been ensured (the ratio F_{drop}/F_{rise} varies within wide limits but is not less than 0.29). Nevertheless, it must be noted that damage to water-wall tubes occurred recently at one GRES.

It is desirable that an investigation be made of circulation in industrial units, in particular, of a boiler with recirculation in the water walls. This system requires further study but may be promising, inasmuch as the upper header of these walls serves as the dividing element. In investigating the circulation, it is desirable to look into the possibility of some reduction in metal expenditure on the nonheated tubes of the downward-flow system.

At all existing high-pressure installations, practically scaleless boiler operation was ensured, which confirms that it is possible to employ water-wall headers without any hatchways, given good operation.

Superheaters

At almost all high-pressure electric power stations, the steam temperature during trial runs and during the initial period of operation was excessively high. One cause of this was incorrect furnace conditions. Sometimes high superheat was also caused by low feedwater temperature, due to absence of high-pressure preheaters.

Even temperature distribution of superheated steam along the coils in high-pressure installations is vital to reliable superheater operation. In USSR power stations, the following steps are taken to ensure this: transfer of superheater tubes from one half of the boiler to the other; mixing the steam by means of special headers and connecting pipes; increasing the steam velocity, especially on the outlet side (boiler installations of the Podol'sk and Taganrog Boiler Plants). These ensure more uniform steam distribution in the coils most subjected to heat stresses.

Installation of supplementary mixing headers carried out in 1948 during reconstruction of a superheater at one TETs (Heat and Power Station) enabled the temperature spread of the coils to decrease from approximately 100 to 20°C.

An example of high-temperature variation is the case of the superheater of a boiler fired on milled peat, in which the temperature difference in individual coils exceeded 100°C in the first period of operation. Satisfactory temperature distribution with a spread of 20-30°C was achieved only after a general readjustment of furnace conditions. In particular, it was possible to influence the position of the flame in the shaft-pulverizer furnace by means of part of the secondary air which is delivered through the nozzle to the back corners of the furnace. It was found that the flame was pressed to the side walls when the corner air was shut off, but was thrust toward the center of the furnace when the corner air was on.

Trial runs with installed boiler units showed that nonuniform temperature distribution along the superheater coils should be taken into account in the design stage and provision made for adjusting it during operation. Fitting thermocouples on each coil or at least on alternate coils was necessary during the trial runs of each high-pressure unit. Moreover, it is very desirable for future operational guidance, to show the temperature measurement of the coils under the most stress on the stoker's control panel.

Boiler units built or reconstructed in the USSR as a rule have combined systems for connecting the superheaters. Diverse as the systems may be, in almost all cases the principle of removing the outlet superheat turns and the final steam-drying zone from the hottest gases has been maintained.

In most high-pressure installations put into operation after the war, work has been done on standardization of superheated steam temperature. The steps taken to achieve this may be broken down into the following groups:

1. Reducing contact between the superheater heating surface and the hot gases by by-passing part of the gases. Usually some of the brickwork under the superheater is removed and part of the gases passes through the opening thus formed. This method, as is well known from experience of medium-pressure boiler adjustment, is often ineffective. This is also confirmed by operation of a high-pressure boiler at a GRES on lean coal and "ASh" fuel.

2. Insulating part of the superheater heating surface. For example, one station insulated the bends in the coils; another, the overhung superheater tubes, etc.

3. Reducing the heating surface of the superheater. In most cases, the length of each coil is reduced and, more rarely, some of the coils are completely removed. The latter method is less recommended, since it leads to the formation of gas passages and excessive heating of the coils adjacent to them.

Reducing the heating surface is a radical measure for reducing superheat At the same time, it has to be used in extreme cases because of the labor and inconvenience involved in modifying existing boilers. In addition, after an over-all adjustment of the unit and an increase in the feedwater temperature is made, the superheat may be insufficient.

Regulation of Superheat

Fluctuations in the temperature of superheated steam are caused by changes in the load of the unit, the quality of the fuel, the temperature of the feedwater, excess air, the amount of dirt on the furnace water walls, etc. The dependence of superheat on the above-mentioned factors becomes more pronounced as steam pressure and temperature increases, and as the temperature zone surrounding a convection superheater decreases.

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A superheater having radiation and convection sections with a suitable ratio between the heating surfaces of the sections can produce a superheat which varies little with alterations in load and changes in fuel. Only minor adjustments are required; the controls are easier and automatic operation is simpler.

It follows that for high-pressure boilers operating on the fuels used in USSR power stations, it is advisable to manufacture radiation-convection superheaters with superheat regulators.

Boiler plants with natural circulation and radiation convection superheaters have now begun to be used, and this year will afford opportunities for obtaining practical experience with the peculiarities of this design.

The difficulties encountered in adjusting boilers put into service at one station without superheat regulators provided confirmation of the fact that superheat regulation is indispensable on high-pressure boilers.

Except for one GRES, all our power stations have desuperheaters on their high-pressure units. Experience has shown that spray desuperheaters inserted in series have operated satisfactorily. They are useful for units where it is not possible to work with chemically purified water, as the installation of special high-pressure pumps and leads would be too complicated.

After elimination of the initial defects, surface desuperheaters in which the steam is cooled with boiler water are functioning satisfactorily at two stations. They should be produced at one of the machine-building plants.

When a desuperheater is fitted on the saturated steam side, mixing headers should be fitted next to it. Fitting a desuperheater with feedwater cooling in series with the superheater has serious drawbacks which have prevented our factories from adopting this system.

Water Supply and Carry-Over of Salts With the Steam

It has not been established for boilers with a pressure of 100 atm and above to what extent the quality of the steam deteriorates when the boilers use softened water for make-up feed. The matter is rendered more complicated by the definitely proven property of steam at and over 100 atm to dissolve and carry-over in a state of molecular dispersion certain substances, e.g., silica, caustic soda, and sodium chloride.

Although most boilers operate on a condensate-distillate system, some units are now supplied with make-up feed consisting of chemically purified water. In both cases salt carry-over is observed. The salts are precipitated mainly on turbine blades but sometimes are partially precipitated in superheater tubes.

Most difficulties are connected with silica being carried over from the boilers. It forms deposits (sometimes soluble, sometimes insoluble) on the turbine blades. Insoluble precipitates, according to data from VTI (All-Union Thermotechnical Institute) Water Laboratory, are formed in cases where the molar ratio of N_2O (hydrate) to SiO_2 in the boiler water is less than unity.

The salt carry-over situation is rendered more complicated by the fact that, in some stations, cases still occur of silica entering via leaks in turbine condensers and other equipment on chemically purified water lines.

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It has not yet been decided which are the best separation systems and boiler apparatus. The operational features of individual elements of these systems have not yet been fully studied. Some information in this field may be gleaned from trials performed by VTI on 65-atm boilers, with divided drums, using chemically purified water. In the first stage of the experiment, it was possible, using a supplementary "calming" apparatus, to raise the permissible salt content of the boiler water from 600 to 1,100 mg/l.

The operation of a boiler on the stage evaporation system was investigated in one unit of the same installation. The ratio of the salt content of the fresh and salt sections was approximately 1.3, and the salt content of the blow-off water was about 3,000 mg/l. Research on water conditions must be continued.

Checking steam quality is not always done as it should be. In particular, many installations have no salinometers for continuously indicating the quality of the steam and boiler water.

VTI has devised methods for checking steam salt content (sorption, partial condensation) and steam moisture (throttling calorimeter) which are especially effective when carrying out boiler trials.

Water Economizers

Most economizer breakdowns were caused by cracks forming in welded seams due to defective factory and installation welding. In addition, some economizer defects were due to defects of design or system. At the boiler units of one GRES, the outlet pipes from the economizers run along the outer wall of the reversing chamber, then along the top of the boiler, and down to the drum (Figure 7). In the upflow part of the tubes, the water movement is determined by the pump head (pressure), being equal to 0.3 m/sec, and in the downflow part, which is 3.5 m high, by the weight of the column of liquid. When only frictional resistance is present and the tubes are full, the speed should be over 3 m/sec.

Under these circumstances, there are considerable variations in the hydraulic conditions in the various coils, with a high percentage of water evaporation in some tubes; during insufficiently stable furnace operation this would lead to overheating and tube failure. The tubes of an economizer used to be subjected to especially severe conditions when raising steam. Tube failures ceased after arrangements were made to recirculate water in the economizers while raising steam, and after changing over to gas firing.

In another GRES boiler, after a 2-week trial, it was found that the diameter of the outlet tubes of the economizer had increased from 38 mm to 40-44 mm. These tubes pass in front of the superheater, i.e., in the area of gases with a temperature of about 900°C (Figure 8).

The fact that they overheated and expanded may be attributed to some or all of the following reasons:

1. Insufficient cooling by the water pumped through the economizer while raising steam.

2. Insufficient delivery of water to the boiler during uneven feeding of the unit.

3. Insufficient water reaching the economizer when pumping large quantities of water through the desuperheater and thence directly into the boiler drum.

The thermal and hydraulic operation of a water economizer is complicated by a high degree of evaporation and low-water velocities. At the designed load, if all the water passes through an economizer, its velocity is 0.36 m/sec and degree of evaporation about 19%. At high superheat, when there is a heavy load on the desuperheater, the flow of water through the economizer will be less than the steam load on the boiler; water velocities will be lower and the percentage evaporation higher.

If the heat content of the water in the economizer is increased considerably, mixing headers do not need to be provided. Under these conditions, the temperature variation in the coils may be considerable even if the outlet water from the desuperheaters is made to pass through the economizer.

The cast-iron, ribbed, high-pressure air preheaters help to reduce corrosion along the first portion of the air path and lessen the danger of distortion of the hottest part of the air preheater. No accumulation of dirt was observed on these preheaters. In this connection, it must be considered necessary to manufacture cast-iron elements of more rational design to replace worn elements in existing units and to outfit new units.

Heat Control and Automatic Operation

Considering the operating conditions of separate elements of high-pressure boiler units, the operation of boilers without a complete set of the control and measuring instruments prescribed by the "Rules for Technical Operation" is not permissible. The list of measurements and instruments prescribed by the above-mentioned Rules should be increased as follows for medium pressure units:

1. When the superheater is divided into two stages with a desuperheater between them:

   a. Measurement of steam temperature after the first stage of the steam path.

   b. Measurement of the temperature of the cooling water beyond the desuperheater point when feedwater is used for cooling.

   c. Measurement of the expenditure of cooling water for surface desuperheaters with feedwater cooling and for spray desuperheaters.

   d. Measurement of steam temperature after the desuperheater.

2. When the water economizer or air preheater is divided into two stages:

   a. Measurement of gas and air (water) temperatures after each stage.

   b. Measurement of the rarefaction after each stage.

3. Level indicators, registering, preferably with signaling for extreme positions of the level.

4. Reduced level indication for all boilers.

Accessory Equipment

The decisive trend toward headers with no hatchways and the least possible number of flanges in pipelines in the new Soviet high-pressure installations has been fully justified in practice. Many breakdowns due to defects in equipment which took place during the initial period of operation will be eliminated in the future. However, there are still many defects in the operation of imported, and sometimes domestic accessory equipment, as follows:

1. Valves often leak when shut (this applies especially to draining equipment).

2. Instances of poor quality casting arise in the casings of equipment made by the Venyukovo Accessory Equipment Plant (Venyukovskiy Armaturnyy Zavod). Due to insufficient testing of equipment at the plant, casting defects were discovered in many cases only after installations had been put into service.

3. Seats and lids of steam valves of the Venyukovo Plant made from Mark "35 KhMYuA" steel wear rapidly owing to the low erosion resistance of this steel. The upper layer of nitrided metal is easily worn down when reseating the valve and consequently does not protect the steel from steam erosion.

4. Loosening of the seat, which screws directly into the valve casing, occurs after the valve has been closed several times. In water valves, this defect can be minimized by making the seats of EZh-3 steel, which has a lower coefficient of linear expansion than the steel of which the casing is made.

5. Cracks going deep into the body occur in reinforcing ribs.

6. The stuffing box packing of many valves wears out rapidly. For this reason, it is desirable to organize centralized plant manufacture of packing.

The operation of equipment is complicated by the absence of instructions regarding installation, acceptance tests, and repair (reseating fitted surfaces, preparing stuffing box packing, assembly of stuffing box, etc.). Such instructions should be compiled by the manufacturing plant and supplemented at the stations. Moreover, the plant must deliver special tools along with the equipment (e.g., wrenches for screwing down seats).

Firing

Firing is a specific and important operational procedure. Typical firing graphs are shown in Figure 9.

As a rule, during firing the superheater tubes are blown through with steam as soon as the pressure reaches 5-10 atm and water is pumped through the economizer (curves 2,4,5). In the case given, the total firing period was 4 hr 20 min from starting the flue gas pump to connecting the boiler in parallel with other boilers and putting on load.

Firing results in appreciable losses of fuel and condensate, especially when of long duration (8 hours in some cases). Hence, there arises the necessity for economizing in fuel and water by reducing the number of starts and shutdowns to a minimum, reducing the length of the firing period to 4-5 hr, and using the steam blown through the superheaters in the medium-pressure network or in the heat system of the high-pressure installation.

Only one USSR GRES fires its boilers with the superheater full of water. As can be seen from curves 1 and 3 of Figure 9, it takes 3 hr 20 min to raise the pressure to 80 atm and open the main steam valve. During the first 2 hr 10 min, the superheater is filled with water, which is then removed by blowing through with steam from the boiler.

Uniform and complete removal of water can be assured with horizontally drained superheaters. Water pockets may remain in vertical coils after blowing through. The cooling of coils with such pockets during firing may be insufficient; it is therefore undesirable to raise steam with vertical superheaters full of water.

Conclusion

Much work remains to be done before high-pressure boiler units are thoroughly understood. Much scientific research is required, including investigations on circulation, separation, and stage evaporation under high-pressure conditions. Circuits with recirculation in the water-wall screening tubes and the production of high quality steam in one-drum boilers are of particular interest. Much work should be done on the water conditions in high-pressure boilers, especially on studying the behavior of silica in boilers, superheaters, and turbines. A study should be made of the properties of metals subjected for lengthy periods to the action of high pressure and temperatures; complex tests should be carried out on a number of boiler units, etc.

However, it can be stated, on the basis of existing experience, that high-pressure boiler techniques have been mastered more rapidly and successfully in our country in the postwar period than they have abroad. Numerous difficulties which seemed very great in the beginning have been overcome.

At the same time, the distinguishing characteristic of high-pressure equipment has been found to be the necessity for better operation, i.e., more care in meeting the requirements which have already been formulated as a result of experience with medium-pressure boiler installations.

The boiler-building industry must study existing experience with high-pressure boiler installations to produce still more improved, reliable and economical boiler units, accessory equipment, and auxiliary units.

(The above article includes data from VTI reports at the Scientific and Technical Session of the Commission for High-Parameter Steam, Academy of Sciences USSR, presented on 30 March 1949.)

[Appended figures follow:]

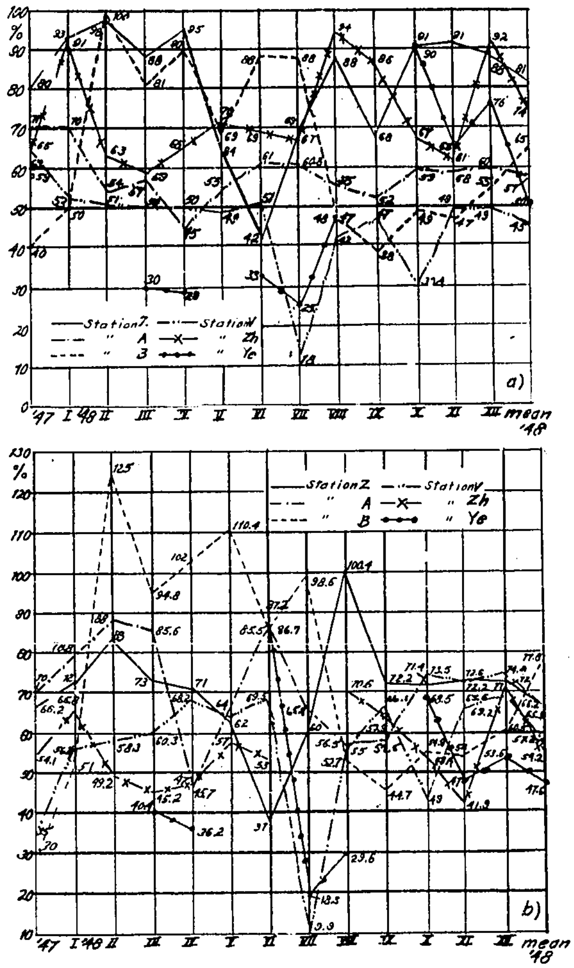

Figure 1. Degree of Utilization of High-Pressure Boiler Units.
(a) Operating time factor, (b) Utilization factor

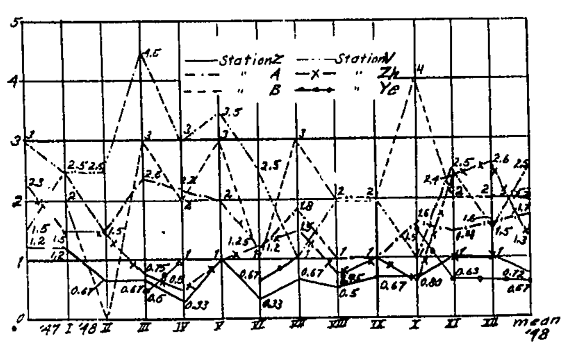

Figure 2. Number of Firings of One Boiler Unit in a Month

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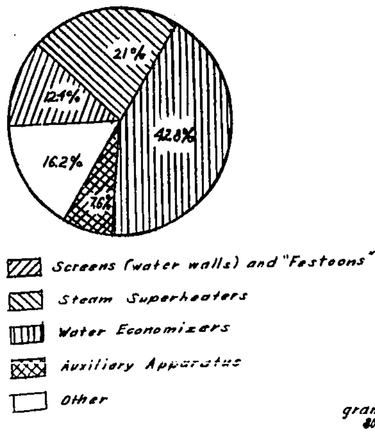

Figure 3. Distribution of Breakdowns of Boiler Unit Components

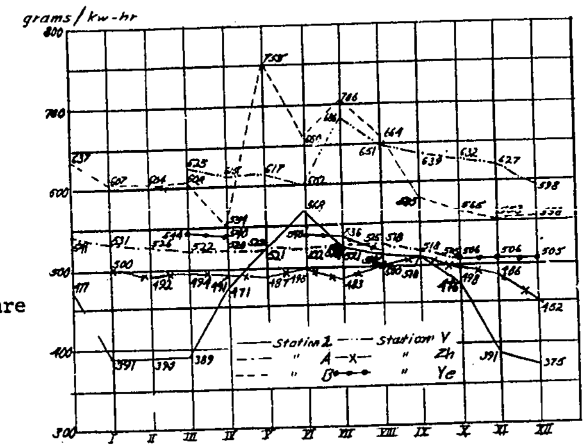

Figure 4. Specific Expenditure of Standard Fuel

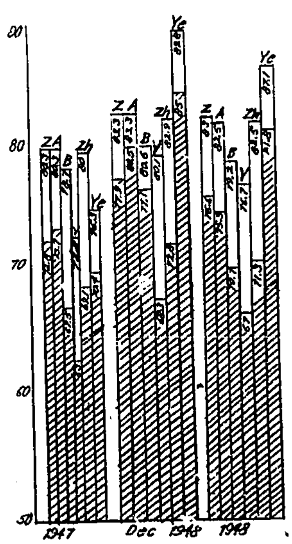

Figure 5. Efficiency of Boiler Installations in Various High-Pressure Stations. The full column height represents the gross efficiency of the boiler, while the crosshatched part is the net boiler efficiency. Data for Station Zh is the data for the whole station.

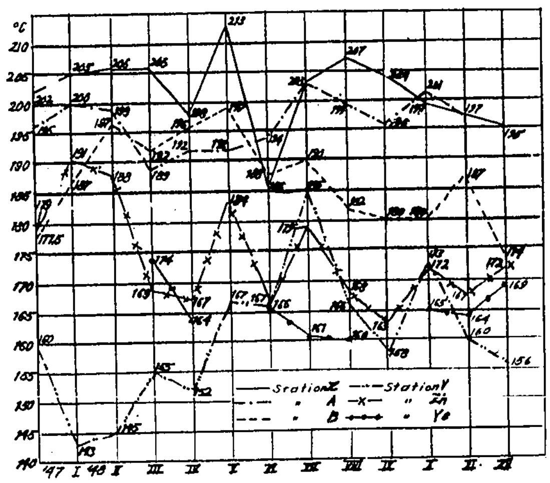

Figure 6. Temperature of Flue Gases

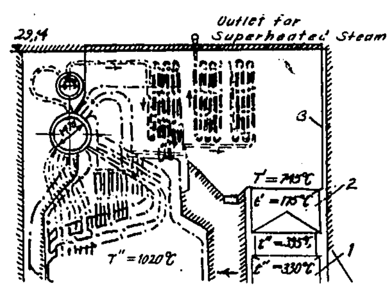

Figure 7. Boiler Unit Layout. (1) Air preheaters, (2) Water economizer, (3) Outlet tubes

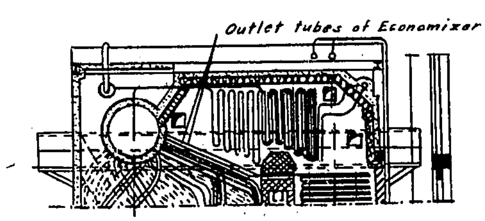

Figure 8. Mounting of Water Economizer in Boiler Unit

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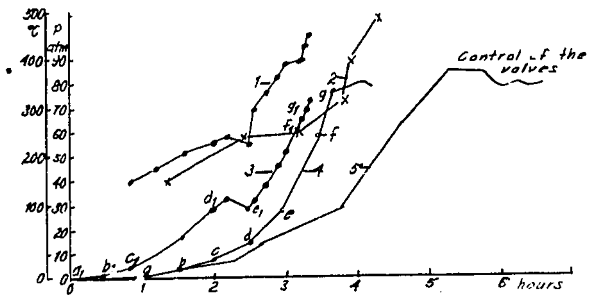

Figure 9. Graph of Firing High-Pressure Boiler Units

1-- Steam temperature in firing boiler unit of Station Ye; 2-- Steam temperature in firing boiler unit of Station A (reserve boiler); 3-- Steam pressure while firing unit of Station Ye; 4-- Steam pressure while firing unit of Sation A (reserve unit); 5-- Steam pressure while firing unit of Station A from cold state.

a-- Air shut off; b-- Covering and blowing through; c-- Start of forced draft ventilators and opening tubes encircling gate valves; d-- Blowing through boiler; g-- Connecting in the boiler.

a_1-- Igniting the muffle jets; b_1-- Air to superheater turned off; c_1-- Air to boiler dome turned off; d_1-- Closing the filler tubes under the drum and opening the drain valves of the superheater; e_1-- Heating up the main steam pipe to the steam header; f_1-- Closing the tubes between the steam dome and superheater; opening the blowoff to atmosphere, closing the drain valves of the superheater, starting the dust (fuel) feeder; g_1-- Opening the drains at the main steam valve and opening the main steam valve.

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